

## Introduction

The need for research into alternative renewable energy sources has become a growing issue in the recent years. A combination of wind and wave power could reduce the installation and maintenance cost by occupying common infrastructures. The aim of this master thesis was therefore to elaborate a design proposal, which combines these two power sources and to calculate the power output of the proposed system.

## Main Challenges

- ▶ Wave Energy Converters (WEC's) need offshore sites with high wave energy distribution, while offshore wind turbines operate best when exposed to as little wave energy as possible.
- ▶ The power produced by WEC's and wind turbines needs somehow to be stored. Otherwise the power devices have to be stopped or disconnected from the power grid in times of decreasing power demand onshore. (for ex. at night time).

## The Proposal

The proposed solution does not combine the two power sources directly, but rather through a common underwater energy storage tank. The idea is to produce power by extracting energy from sea water flowing into the tank. To exploit the pressure on the seabed in practice, the power is captured in a Kaplan turbine, as in a normal pumped-storage hydroelectricity power plant. The water flowing into the tanks is then directly pumped out by wind driven centrifugal pumps and wave driven piston pumps.

This solution introduces several potential benefits:

- ▶ The wind turbine can be installed at deep offshore sites, while the WEC can be installed near shore, at sites with high wave energy distributions. The power cable connecting the wind turbine to the centrifugal pump is, however, expensive. The distance between the turbine and pump should therefore be kept as short as possible.
- ▶ The installation of expensive batteries are not needed since the tanks store the energy from both wind and waves.
- ▶ Only one power cable connecting the energy storage tank and the power supply system onshore is needed. This should cut down the total power cable length.
- ▶ The tanks can be pumped empty at night time, when the power demand is lowest in order to store potential energy for times with higher power demands.
- ▶ Several tanks can be installed with power producing turbines in between to harvest as much kinetic energy as possible.
- ▶ Generating power through the Kaplan turbine and pumping sea water can be done simultaneously by implementing valves in between the energy storage tanks.
- ▶ Already existing offshore wind turbines can be connected to the system.

## The Concept

Figure 1 shows a simple sketch of the combined wind and wave power concept, which was developed in this thesis.

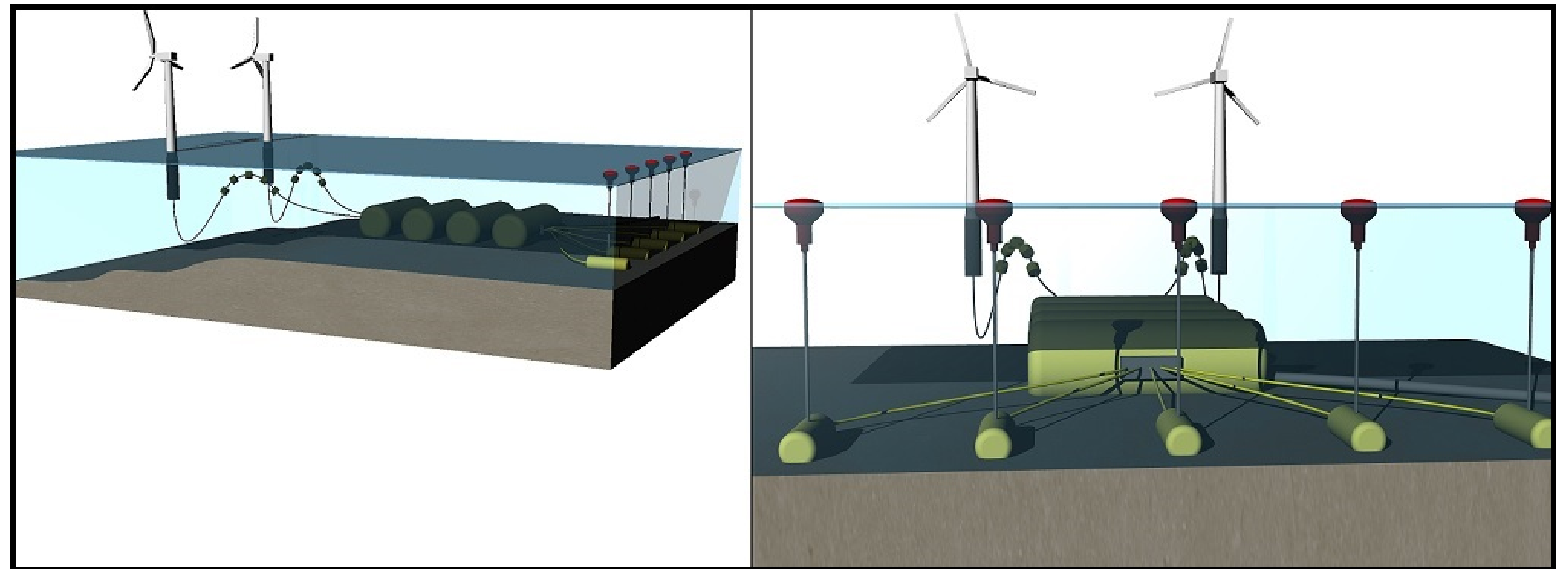


Fig. 1: The Developed Concept (illustration made in Rhino3D)

## Power Analysis

The aerodynamics of the wind turbine blades (for a chosen offshore site with mean wind speed of 12 [m/s]) were designed in MatLab. This was done by using Beam Element Momentum (BEM) theory. To analyse the power efficiency for varying wind speeds the turbine blades were imported to the software ASHES.

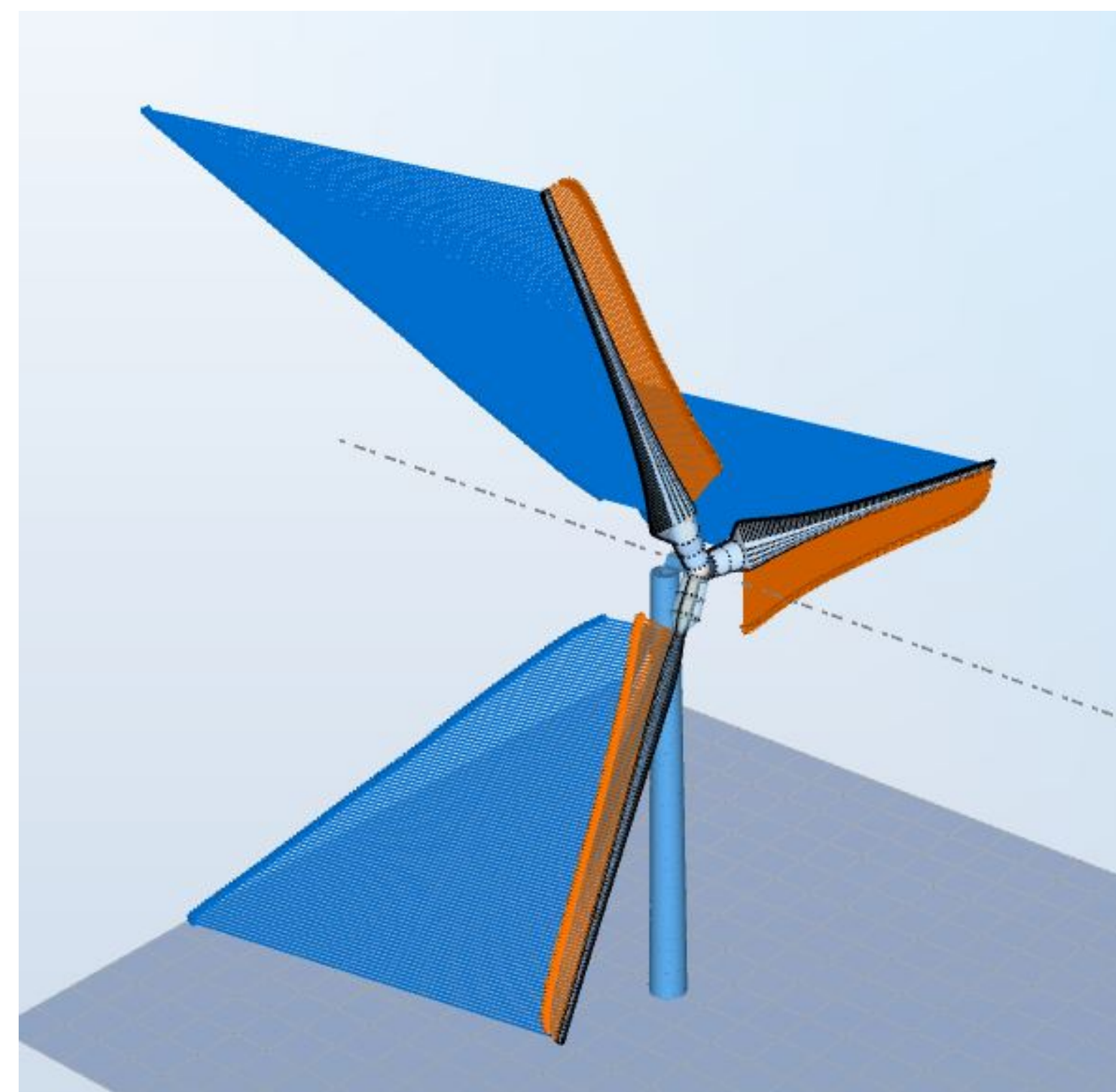


Fig. 2: The Designed Wind Turbine (ASHES)

To analyse the wave power output for each sea state the Swedish/Norwegian CorPower WEC was chosen. This WEC has shown promising results and combines modern with proven technologies. To compute the wave loads and motions of the WEC the software WAMIT was used.

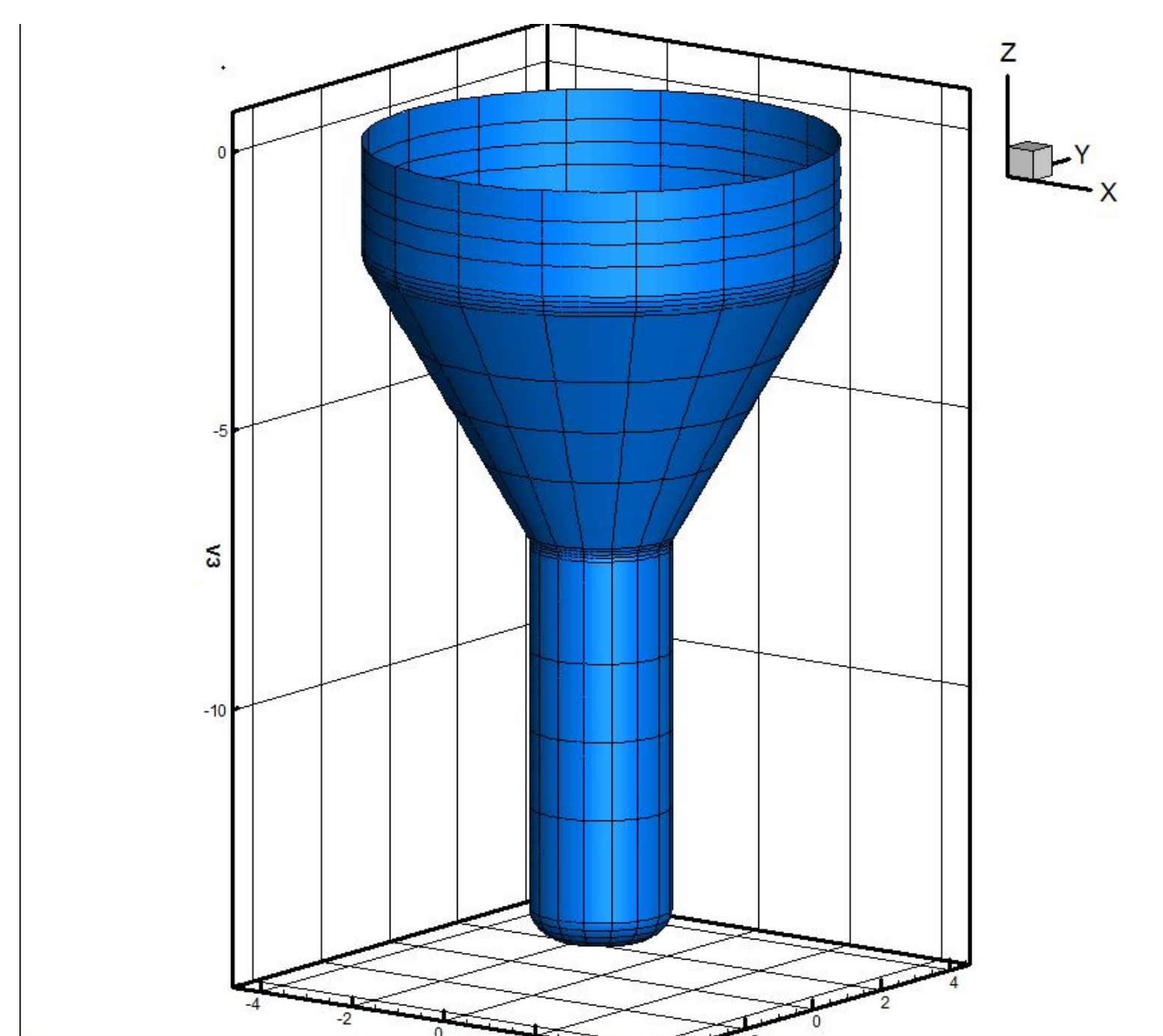


Fig. 3: The Wave Energy Converter (WAMIT)

Additionally calculations in MatLab were made to include a Power Take Off machinery (PTO), which extracts the energy from the waves.

## Governing Equations

The maximum average power that can be captured in the wind is given by [1]:

$$\bar{P} = \frac{1}{2} \rho_{air} U^3 \pi R^2 C_p [W] \quad (1)$$

where  $U$  is the wind speed,  $R$  the radius of the turbine, and  $C_p$  the power coefficient restricted by the Betz Limit.

The average captured wave power in heave is given in frequency-domain as [2]:

$$\bar{P} = \frac{1}{2} \frac{B_{PTO} |F_{3a}|^2}{(B_{33} + B_{PTO})^2 + [\omega(m + A_{33}) - \frac{C_{33}}{\omega}]^2} \quad (2)$$

where  $F_{3a}$  is the excitation force amplitude and  $A_{33}$ ,  $B_{33}$  and  $C_{33}$  are the added mass, damping and stiffness coefficients, respectively.  $B_{PTO}$  is the additional damping caused by the PTO extracting the wave energy from the system.

## Conclusion

The question whether it is economical feasible to combine wind and wave power still remains. The CorPower WEC reaches a power output limit at 300kW. The wind turbine investigated in this thesis achieves up to 5MW, which means that one would have to install approximately 16 WEC's to achieve a competitive amount of power. This conclusion should scare off potential investors. Since the investigated WEC is not contributing sufficiently to the total power output of the system, other wave power devices could be examined.

In addition, the installation cost of the total system including the underwater energy storage tanks has to be investigated further.

## References

- [1] Volker Quaschnig: *Regenerative Energiesysteme*, Hanser Verlag Muenchen, Germany (2013)
- [2] Johannes Falnes: *Mechanical Oscillator and its Application for Absorption of Wave Energy*, NTNU, Norway, 2005